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TITLE: Plasma cleaning of chemical vapour deposition tube - by creating deposit-etching plasm using reactant gas and radio frequency element

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BASIC-ABSTRACT:

Wall deposits on a furnace tube used in a film deposition system are removed in situ by creating a deposit-etching plasma within the tube. An etching gas is supplied to the tube and r.f. energy is applied to r.f. elements located along the tube for coupling the energy to the gas to form a deposit-etching plasma.

Cleaning furnace tubes used in low pressure chemical vapour deposition of films, such as Si, silicon oxide and silicon nitride.

Cleaning in situ reduces operating time and costs and increases safety of operation. The cleaning plasma can extended to portions of the tube beyond the r.f. elements by decreasing reactant flow rate, pressure, and/or varying the power.

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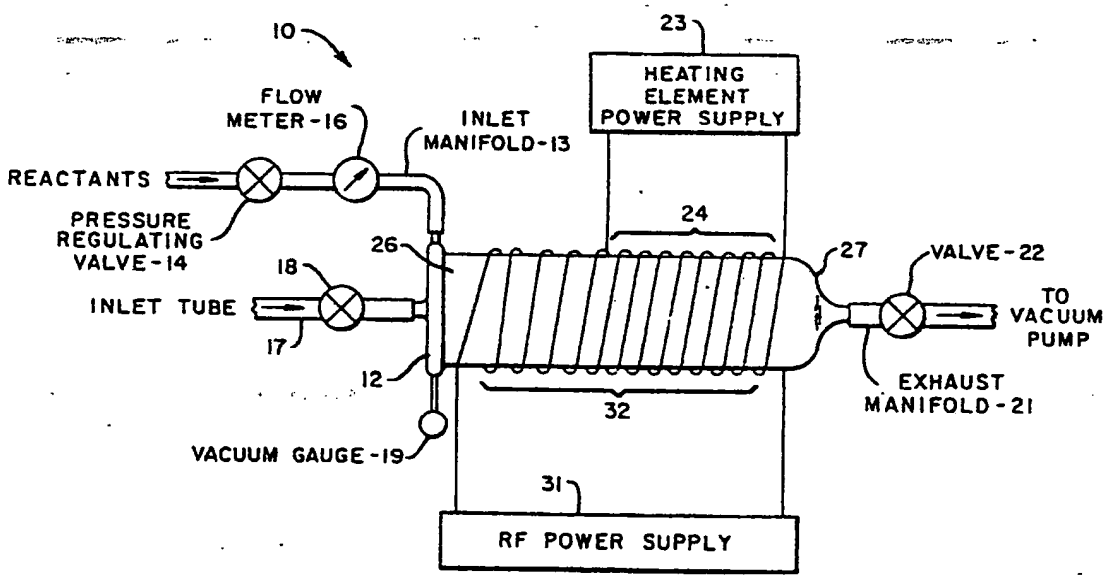

(57) Abstract

Process for cleaning wall deposits from a furnace tube (11) used in a low pressure chemical vapor film deposition system (10). The cleaning of the tube is carried out *in situ* in the furnace by creating a deposit etching plasma within the tube. The plasma is generated by introducing a suitable gas into the tube and applying RF energy to elements (32) located along selected portions of the tube for coupling the RF energy to the gas.

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LPCVD SYSTEMS HAVING IN SITU PLASMA CLEANING

Technical Field

The invention relates to the cleaning of deposition systems and, more particularly, to cleaning furnace tubes used for chemical vapor deposition of films such as silicon (both polycrystalline and monocrystalline), silicon oxide and silicon nitride.

Background Art

Silicon, silicon oxide and silicon nitride films are widely used in microelectronics technology. Their deposition can be by any one of a number of processes including plasma deposition, chemical vapor deposition, etc. Low pressure, chemical vapor deposition (LPCVD) using large-tube furnaces combines the deposition control and quality which is characteristic of CVD processes with the ability to process large wafer loads. However, it is typical that after even a few deposition cycles, the interior wall(s) of the furnace tube becomes (become) coated with the film constituents and other contaminants. The result is flaking of the deposit or cracking of the tube due to the different thermal expansions of the tube material, usually quartz, and the deposit. Furthermore, in depositing silicon nitride, a powder is frequently deposited in the cooler regions of the tube such as at the loading door at the entrance to the tube. Deposits such as these are a source of particulates which alter the deposition rate and contaminate the deposited film, and cause defects in the form of pinholes, granular surface regions, etc.

Because of the above problems and to avoid low yields during semiconductor device fabrication, the furnace tube must be cleaned periodically. Cleaning typically involves allowing the tube to cool; removing the tube from the furnace; cleaning the tube by etching

for several hours in a wet bath containing, e.g., a 1:1 ratio by volume of concentrated hydrofluoric and nitric acids; rinsing the tube in water; replacing the tube; and resetting the deposition temperature cycle, which is perturbed when the tube is removed. After replacing the tube, the furnace is heated to 100°C or higher to vaporize any remaining water. This cleaning process is time-consuming and involves the risks of tube breakage and handling corrosive cleaning materials.

Plasma furnaces or CVD reactor furnaces have been used to perform different operations in the reactor by altering the reactor atmosphere. For example, U. S. 3,940,506 issued February 24, 1976 to Heinecke teaches etching silicon dioxide or depositing a polymer by controlling the concentration of reducing species, such as hydrogen, in a plasma etchant which contains fluorine and carbon. U. S. 3,867,216 issued February 18, 1975 to Jacob teaches etching oxide or nitride without degrading a photoresist mask, and then stripping the mask, by varying the oxygen ratio in a plasma-forming binary mixture of oxygen and halocarbon.

Furthermore, etching and deposition of the same material in the same apparatus is known. U. S. 3,945,846 issued March 23, 1976 to Goldsmith et al uses the same reactor furnace to etch silicon and hydrochloric acid, then deposit epitaxial silicon by the reduction of dichlorosilane, both at 1,050°C. to 1,200°C. U. S. 3,914,127 issued October 21, 1975 to Buss et al teaches the use of a plasma reactor to perform several of the steps of fabricating a CCD device, including sequentially etching an oxide or nitride film in a plasma-containing carbon tetrafluoride at less than 150°C, then depositing oxide or nitride from a plasma at 200°C to 400°C.

Thus, in situ cleaning of wafers has been done in small deposition systems and in small plasma reactors. Here, the addition of plasma cleaning capa-

bility has been relatively straightforward because of the small size of such systems and because the systems are built with the facility for plasma operation.

Disclosure of the Invention

It is an object of the invention to use plasma techniques for cleaning in situ large furnace tubes used in low pressure chemical vapor film deposition systems.

Thus, according to the invention, there is provided a process for cleaning wall deposits from a furnace tube used in a film deposition furnace system, the tube having a gas inlet end and a gas exit end, the improvement wherein the tube is cleaned in situ in the furnace, comprising: maintaining the tube interior at subatmospheric pressure; supplying gas to the gas inlet end of the tube, the gas being suitable for creating a deposit-etching plasma; generating RF energy; and applying the RF energy to RF element means located along a selected portion of the tube adjacent the gas inlet end for coupling the RF energy to the gas to form a deposit-etching plasma over at least the selected portion of the tube.

It should be clear that the cleaning of a furnace tube without its removal from the furnace reduces operating time and costs and increases safety of operation. Also, the use of plasma cleaning is advantageous, since plasma is economical, low in contaminants, non-toxic and non-corrosive. The invention may be used to clean dielectric films such as silicon oxide and silicon nitride, conductor films, and semiconductor films such as silicon. The cleaning plasma can be extended outside the selected portion of the tube occupied by the RF element by decreasing the reactant flow rate, decreasing the pressure, and/or varying the power.

Brief Description of the Drawing

One embodiment of the invention will now be described, by way of example, with reference to the

accompanying drawings in which:

Figs. 1-4 are schematic representations of alternative embodiments of LPCVD systems which have in situ, plasma self-cleaning capability.

Fig. 5 is a cross-sectional representation of the furnace tube used in practicing the invention, showing zone dimensions and means for applying an electric field to the furnace tube.

Best Mode for Carrying out the Invention

Fig. 1 is a schematic illustration of one embodiment of apparatus 10 for both depositing films such as silicon nitride using LPCVD, and also for cleaning the furnace tube(s) in which deposition takes place, in situ, using a plasma etch.

The apparatus 10 comprises an LPCVD furnace system including a tube 11, typically made of fused quartz, having a cover 12 at the inlet end 26 of the tube and a gas inlet manifold 13. Gaseous reactants are admitted to the tube 11 via the inlet manifold 13 and flow rates are controlled by a pressure-regulating valve 14 and read from a flow meter 16, both of which are connected to the inlet manifold. Gas inlet 17, which is opened and closed by valve 18, connects the interior of the tube 11 to a source of inert gas, such as nitrogen. Vacuum gauge 19 is connected to the interior of the tube adjacent the inlet end 26 for providing readings of the internal pressure.

The opposite, exhaust end 27 of the tube is connected to an exhaust manifold 21, to which is connected a gate valve 22 for controlling the connection of the tube 11 to a vacuum pump (not shown). The path of movement of gases along the tube is from the inlet end 26 to the exhaust end 27. The terms "downstream" or "upstream" refer to this flow.

A power supply 23 provides current to electric resistance heating coils 24 for heating the internal

volume of the tube 11 and for pyrolytically depositing silicon, silicon nitride, silicon oxide or other films from the reactants entering via inlet manifold 13.

An example of a furnace system which employs the type of arrangement shown in Fig. 1 is the model 4000S-72.00, available from Thermco Products Corp., 1465 No. Batavia St., Orange, California 92668. This furnace system contains four interchangeable furnace tubes 11, which are supplied, heated and evacuated as shown in Fig. 1. The tubes typically are about 229 centimeters long and about 13.5 centimeters in diameter. Each tube can hold approximately 120 10.2 centimeters diameter wafers. The heating rods 24 span approximately the 178-191 centimeters of tube length adjacent the exit end 27. This length is sufficient to provide reproducible deposition along the length of the deposition zone. Referring to Fig. 5, deposition zone 52 is an approximately 76 centimeter long central region having a closely controlled temperature profile. The deposition zone is flanked by cooler, front and rear zones 53 and 54.

Referring to Fig. 1, in accordance with this invention, an RF plasma-generating element (or elements) is (are) provided along a selected length of the tube to provide a plasma for cleaning the aforementioned deposit from at least the selected length. In the embodiment of the invention shown in Fig. 1, RF energy is supplied by a power supply 31 and the RF energy is coupled to the tube 11 by an RF element in the form of an induction coil 32 which surrounds the tube and extends along substantially the length of the tube. The RF energy generates an etching plasma when suitable reactants, typically a halocarbon and an oxidant, are admitted via inlet manifold 13. The reactant gas, reactant gas flow rate, RF power, and internal pressure control the removal rate or etch rate provided by the plasma. For example, the type of reactant gas (gases)

can be selected -- such as by selecting the type of halocarbon (freon) and the ratio of halocarbon to oxygen -- to provide the optimum etch rates for different films. Although all experimentation has been done at a temperature of about 750°C and thus, no data has been taken as to the effect of temperature on etching, etching rate and cleaning are increased as the temperature is increased.

The RF heating element is not limited to an induction coil 32. In another embodiment, shown in Fig. 2, the RF heating element is a pair of capacitor plates 33-33 which capacitively couple RF power from supply 34 to the tube 11. The plates 33-33 can be of platinum or tungsten or other high-melting point material which is plated, painted or otherwise applied to the tube 11. Alternatively, plates 33-33 can be mounted about the outside of the tube. The plate area can be varied along the length of the tube 11 to vary the RF power profile along the tube. Capacitive coupling is thought (1) to be accompanied by higher temperatures than is inductive coupling and (2) to create more collisions with the tube walls than does inductive coupling. Both features should provide enhanced cleaning ability.

In still another embodiment of the invention, plasma-creating energy can be applied to the portion of the furnace tube 11 encompassed by the RF coupling element 24 by coupling the RF power directly to the element. As shown in Fig. 3, RF power supply 36 is coupled to the heating element 24 by matching network 37. A separate RF power supply 38 is coupled to RF element 39, which may be a coil (similar to coil 32 of Fig. 1) or capacitive plates (similar to plates 33-33 of Fig. 2), to clean the portion of the tube in front of heating element 24.

An important feature of the invention arises from the discovery that the RF coupling element (coil,

plates, etc.) need not span the entire length of the tube in order to clean along the entire length of the tube. Indeed, plasma techniques can be used to clean the entire tube, even if a partial-length RF coupling element encompasses substantially less than the tube length. To accomplish this, and referring to Fig. 4, the partial-length RF coupling element 41 is positioned adjacent the front end 26 of the tube. Then, by controlling the etch parameters, the plasma generated by element 41 and power supply 42 can be extended toward the rear 27 of the tube.

Alternatively, or in addition to the embodiments of Figs. 1-4, a DC or AC electric field could be applied by power supply 56 between the grounded door 12 and an electrode 57 inserted in the tube 11 through the exhaust manifold 21. See Fig. 5. By this means the charge particles can be accelerated towards the deposition zone by the appropriate selection of flow pressure and applied voltage. The accelerated particles will in turn produce the more active species necessary to etch or aid in etching the walls of the tube. This arrangement would be particularly helpful in etching the rear zone.

It should be noted that the partial-length RF coupling element 41 is preferably upstream relative to the flow of reactants through the tube 11 in order for the plasma to be extended. That is, positioning the partial-length RF element 41 downstream, proximate the exit end or rear 27 of the tube, would make cleaning the front of the tube more difficult, for the plasma cannot be easily extended upstream.

The following examples utilize the apparatus of Fig. 4.

EXAMPLE 1

In one illustration of numerous choices of deposition procedure, the tube 11 was pre-heated to between 700-850°C, and as many as 120 wafers were

placed in the approximately 76 centimeter long deposition zone 52 (Fig. 5). The cover 12 was then attached, gas inlet tube 17 was closed, and the vacuum pump was used to evacuate the interior of the tube to a pressure of about one micron of mercury. Ammonia (NH_3) was then supplied to the interior of the tube via inlet manifold 13 at a flow rate of between 50-100 sccpm (standard cubic centimeters per minute). Dichlorosilane gas, SiH_2Cl_2 (DCS), was then added at a flow rate of 10-30 sccpm to the ammonia flow to deposit silicon nitride on the partially-processed wafers. Using a furnace tube that had been cleaned using the above-described wet bath etch, these exemplary temperature, flow rate and internal pressure parameters provided an initial silicon nitride deposition rate of about 10 to 50 Angstroms per minute (.001 to .005 microns).

After deposition was complete, the DCS and the ammonia flow were terminated and the pressure was pumped down to about one micron. Then, nitrogen was applied under pressure via the inlet 17 to break the vacuum and permit removal of the wafers.

The above deposition cycle was employed a number of times, each to form 500 Angstrom-thick (0.05 microns thick) silicon nitride films on silicon substrates. The initial deposition rate (using a furnace tube which had been cleaned using the above-described wet, hydrofluoric acid:nitride acid etch) was 19 Angstroms (.0019 microns) per minute. After the numerous deposition cycles, the tube walls were covered by a silicon nitride-containing deposit that was believed to be about 12,000 Angstroms (1.2 microns) thick. This thick deposit (indeed even the much thinner deposit resulting from only a few deposition cycles) is characterized by a change in deposition rate from the 19 Angstroms (.0019 microns) per minute rate (for the clean tube) to 24 Angstroms (.0024 microns) per minute.

The RF plasma arrangement of Fig. 4 was then applied in an attempt to clean the silicon nitride

deposit. The RF coil 41 occupied about 25 cm at the front of the approximately 89 centimeter long front zone 53. As mentioned previously and illustrated in Fig. 5, the Thermco furnace provides an approximately 76 cm long, controlled-temperature deposition zone 52 which is flanked by the cooler, 89 centimeter long front zone 53 and 64 centimeter long rear zone 54. For optimum uniformity of thickness and characteristics, wafer film deposition is confined within the deposition zone. It is common to observe the build-up of an amorphous, soft yellow film in the front zone.

Tube cleaning was attempted using the power supply 42 to inductively apply 400 to 500 watts of RF power to the coil 41, and using the inlet manifold 13 and pressure regulating valve 14 to inlet an etching gas comprising approximately four to seventeen percent by volume oxygen and the rest substantially CF_4 into the tube at a flow rate of 1 to 5 sccpm (standard cubic centimeters per minute) as measured by the flow meter 16. (This gas is available from LFE Corporation, 1601 Trapelo Road, Waltham, Massachusetts under the trade name DE-100). The vacuum pump maintained an internal tube pressure of 100 to 150 microns as measured by the vacuum gauge 19.

After etching for one hour, the yellowish, amorphous deposit was completely removed from the front zone 53, resulting in the clear transparent appearance that is characteristic of fused quartz. In the hotter deposition zone where the deposited silicon nitride was more dense and more etch-resistant, a semi-transparent gold film remained, indicating that the silicon nitride was not completely removed.

EXAMPLE 2

A furnace tube 11 was cleaned using the above-described, conventional wet etch bath technique, then the tube was inserted in the furnace and about twenty five 500 Angstroms silicon nitride deposition cycles were performed using the process of Example 1.

To demonstrate removal of the deposit in the front zone using low RF power, the CF_4-O_2 etching gas of Example 1 was inlet at 50 sccpm and at 200 microns pressure, using only 100 watts of RF power. After a 20 minute etch, the quartz wall in the front zone 53 was translucent, indicating the deposited film had been completely removed.

Then, to demonstrate that cleaning action was occurring outside the front zone, i.e., downstream relative to the coil, a silicon wafer having a 444 Angstrom (.0444 micron) thick silicon nitride film thereon was placed at the center of the deposition zone. The 100 watts of power, 50 sccpm etchant gas flow rate, and 200 micron pressure parameters were again applied, with the result that approximately 35 Angstroms (.0035 microns) of the silicon nitride film were removed in two minutes.

EXAMPLE 3

Again, numerous 500 Angstrom silicon nitride deposition cycles were performed prior to cleaning the tube. Then, a cleaning cycle was initiated, using a CF_4-O_2 etching gas flow rate of 1 to 2 sccpm to reduce the pressure to 100 microns and to extend the etching plasma more effectively into the deposition zone 52. RF power was set at 600 watts. After twenty minutes of etching, the tube was opened and initial inspection indicated that the front zone 53 was completely clean.

Etching was continued, this time using an increased gas flow rate of about 6 sccpm, which resulted in a pressure of 140 microns of mercury. The RF power was 400 watts. The etch time was 15 minutes. Visual inspection of the deposition zone indicated that this zone was much cleaner than before, although there appeared to be a slight residue.

Despite the visual suggestion of a silicon nitride residue, when the furnace tube was used for depositing silicon nitride as described in Example 1, the

deposition rate was 19 Angstroms (.0019 micron) per minute. This is characteristic of the very clean state resulting from the use of the 1:1 $HF:HNO_3$ wet bath cleaning process. This deposition rate was taken as evidence that the 400 watt-11 sccpm flow rate-100 microns pressure etch parameters had in fact produced a plasma which cleaned the deposition zone 52.

EXAMPLE 4

Two silicon wafers were first coated with a silicon nitride film. The film thickness was 644 Angstroms (.0644 micron) and 498 Angstroms (.0498 micron) for wafer No. 1 and wafer No. 2, respectively. The wafers were positioned 25 centimeters apart on a boat which was centered in the deposition zone with the wafers perpendicular to the longitudinal axis of the tube (perpendicular to the direction of flow of the reactants). The wafers were etched for 15 minutes using the CF_4-O_2 etching gas at a flow rate of about 6 sccpm, a pressure of 140 microns, and power of 400 watts. This etch removed about 266 Angstroms (.0266 micron) and 180 Angstroms (.018 micron) of silicon nitride from the first and second wafers, leaving a remaining thickness of 378 Angstroms (.0378 micron) and 311 Angstroms (.0311 micron), respectively. For the 15 minute etch, the average etch rate was thus 18 Angstroms (.0018 micron) per minute for wafer No. 1 (which was located nearer the RF coil 41), and 12 Angstroms (.0012 micron) per minute for wafer No. 2.

The above examples illustrate the following. First, plasma etch techniques can be applied to clean deposits such as silicon nitride from large reactor furnace tubes in situ without removing the tube from the furnace. Secondly, a wide range of power, flow rate, and pressure parameters can be applied not only to clean the tube in the vicinity of the coil, but also, by using an RF element spanning the length of the tube (as shown in Fig. 1), to clean along the entire length

of the tube. Third, by reducing the etchant gas flow rate and/or the interior tube pressure and/or adjusting power, the etching can be extended downstream a considerable distance.

Other types of deposits and layers will be readily removed using the process of this invention. For example, silicon, silicon oxide, tantalum, tantalum nitride and molybdenum are rapidly or moderately etched by CF_4-O_2 etching gas. Furthermore, films and layers of these materials, such as films formed on wafers, can be etched, thus presenting the capability of depositing films, etching the films, and cleaning tube deposits in the same furnace system with minimum handling of the furnace tube. For example, a film such as silicon, silicon oxide or silicon nitride could be deposited on wafers positioned in the tube 11 within the furnace system, then the wafers would be removed from the tube and masked, and the masked wafers would be reinserted in the tube for simultaneously etching the films and cleaning tube deposits.

Examples 2-4 demonstrate the ability to extend the effective etching range by varying the etch parameters. Also, Examples 2-4 demonstrate that an RF element spanning about 25 centimeters of the front zone 53 (the front 89 centimeters of the tube) can be used not only to clean the entire front zone, but also to clean the middle, deposition zone 52. Based upon the lower, 12 Angstrom per minute etch rate (0.0012 microns per minute) of Example 4, the 12,000 Angstrom (1.2 micron) deposit would be completely removed from the deposition zone 52 in about 17 hours. This demonstrates that a coil covering no more than 25 centimeters of the front zone 53 can clean more than two-thirds of the tube within this time span. Also, this demonstrates that a coil covering no more than the front two-thirds of the tube could clean the entire tube. Furthermore, it is believed the 17 hour cleaning time could be considerably

shortened. As the cleaning is in situ and doesn't require disassembly or reassembly of the tube, or drying the tube after the wet etch, the plasma etch could be performed overnight without taking the tube out of production use.

Furthermore, it is thought that the 12 Angstroms per minute etch rate is a very conservative estimate of the rates that can be readily achieved. Also, minimal additional experimentation with the etch parameters, including the etching gas composition, should increase the cleaning capability so that the effective cleaning plasma length is extended and the rate of etch is increased. It is the inventor's thought that it should be readily possible to clean the entire tube 11 in a matter of a few hours using an element which spans the front one-third or at most the front one-half of the tube.

The apparatus of Figs. 1-5 would be useful in a portable RF plasma cleaning. For example, the capacitive plates 33 could be formed on the tube 11, or formed as a separate unit which is attached to the tube 11, or could be a separate unit which is permanently attached to the furnace. A portable RF power source would supply power. A vacuum source would be used to provide pressures of perhaps 0.1 to 1 torr to institute a cleaning procedure for several hours or overnight. At the end of the cleaning, the portable RF source would be disconnected from the plates and, perhaps, moved to another furnace for another cleaning cycle.

Other alternative embodiments of the plasma etching apparatus of Figs. 1-5 will be readily attained by those skilled in the art. For example, instead of using a single coil, separate RF coupling elements may be placed along the front and rear zones of the tube and the etch parameters controlled so that the effective etching extends between the elements and along the length of the tube.

CLAIMS:

1. A process for cleaning wall deposits from a furnace tube (11) used in a film deposition furnace system, the tube (11) having a gas inlet end (26) and a gas exit end (27), characterized by cleaning the tube (11) in situ in the furnace, comprising:

maintaining the tube interior at sub-atmospheric pressure;

supplying gas to the gas inlet end (26) of the tube, the gas being suitable for creating a deposit-etching plasma;

generating RF energy; and

applying the RF energy to RF element means (32, 33, 39, 41) located along a selected portion of the tube adjacent the gas inlet end (26) for coupling the RF energy to the gas to form a deposit-etching plasma over at least the selected portion of the tube.

2. The process of claim 1 wherein at least a film on a substrate positioned within the tube (11) is etched simultaneously with the wall deposits.

3. The process of claim 1 wherein the RF element means (32, 33) spans essentially the length of the tube (11) for generating a deposit-etching plasma along the length of the tube.

4. The process of claim 1, wherein the tube is approximately 229 centimeters long and 12.5 centimeters in diameter and wherein the gas is oxygen and carbon tetrafluoromethane, and wherein the plasma is generated using a gas flow rate of from about 1 to 50 sccpm, 100 to 600 watts RF power, and a subatmospheric pressure of 100 to 200 microns of mercury.

5. The process of claim 1 wherein the plasma is extended downstream of the RF element means (39, 41)

5. (concluded)
by controlling one or more of the flow rate of the reactant gases, the interior tube pressure, and the RF power.

6. The process of claim 1, 2, or 3 wherein the RF element means is selected from a coil (32) or a pair of capacitor plates (33).

7. The process of claim 1 or 5, further comprising applying an electric field within the tube to facilitate forming the deposit-etching plasma.

8. The process of claim 5 wherein the tube is about 229 centimeters in length, the RF element means comprises first and second RF elements adjacent the front (26) and rear (27) ends of the tube, respectively, and wherein the plasma is extended between the first and second elements to encompass the tube length.

9. The process of claim 8 wherein each RF element is a coil (32) or a pair of capacitor plates (33).

10. The process of claim 1, or 4 wherein the RF element means (39, 41) extends over substantially less than the length of the tube and a first pressure, a first gas flow rate, and a first RF power are applied to clean the tube proximate the RF element, and wherein at least one of the pressure, gas flow, and RF power is changed to one of a second, lower pressure, a second, lower gas flow, or a second, higher RF power to extend the plasma toward the exit end (27) of the tube to thereby extend the deposit-etching plasma along the tube.

11. The process of claim 1 or 4 wherein the RF element means (39, 41) spans less than about the

11. (concluded)
front one-third of the tube and the plasma is extended to encompass about two-thirds of the length of the tube.

12. The process of claim 1 or 5 wherein the deposit results from the deposition of silicon nitride, silicon oxide, or silicon.

13. The process of claim 10 wherein the deposit results from the deposition of silicon nitride and the first and second pressures, the first and second gas flow rates, and the first and second RF power are selected from the ranges 100 to 200 microns of mercury, 1 to 50 sccpm, and 100 to 600 watts, respectively.

14. An improved apparatus for cleaning wall deposits from a furnace tube (11) in situ within a furnace system, which comprises:

an RF element (32, 33) provided along a selected length of the furnace tube adjacent an inlet end (26) of the tube;

means for supplying RF energy to the RF element;

pressure means comprising a vacuum pump connected to the exhaust manifold (21) for creating subatmospheric pressure within the tube (11) to clean the wall deposit from at least the selected length; and

means for supplying reactant gases to the inlet end (26) of the furnace tube (11) for creating a deposit-etching plasma.

15. The improved apparatus of claim 14, wherein the RF element is selected from at least one of a coil (32) and a pair of capacitive plates (33).

16. The improved apparatus of claim 14 or 15 wherein the RF element (32, 33) spans essentially the length of the furnace tube.

17. The improved apparatus of claim 14, 15 or 16, further comprising an electrode (57) within the furnace tube for applying an electrical field within the tube.

18. The improved apparatus of claim 14 or 15, further comprising a second RF element, the first and second RF elements being located at opposite ends (26, 27) of the furnace tube.

19. The improved apparatus of claim 14 or 15 wherein the apparatus includes means (24) for heating the furnace tube and wherein RF energy supply means (36, 37) is connected to the furnace heating means (24) for coupling RF energy to the tube.

20. The improved apparatus of claim 18 or 19, further comprising an electrical conductor (57) within the furnace tube (11) for applying an electrical field within the tube.

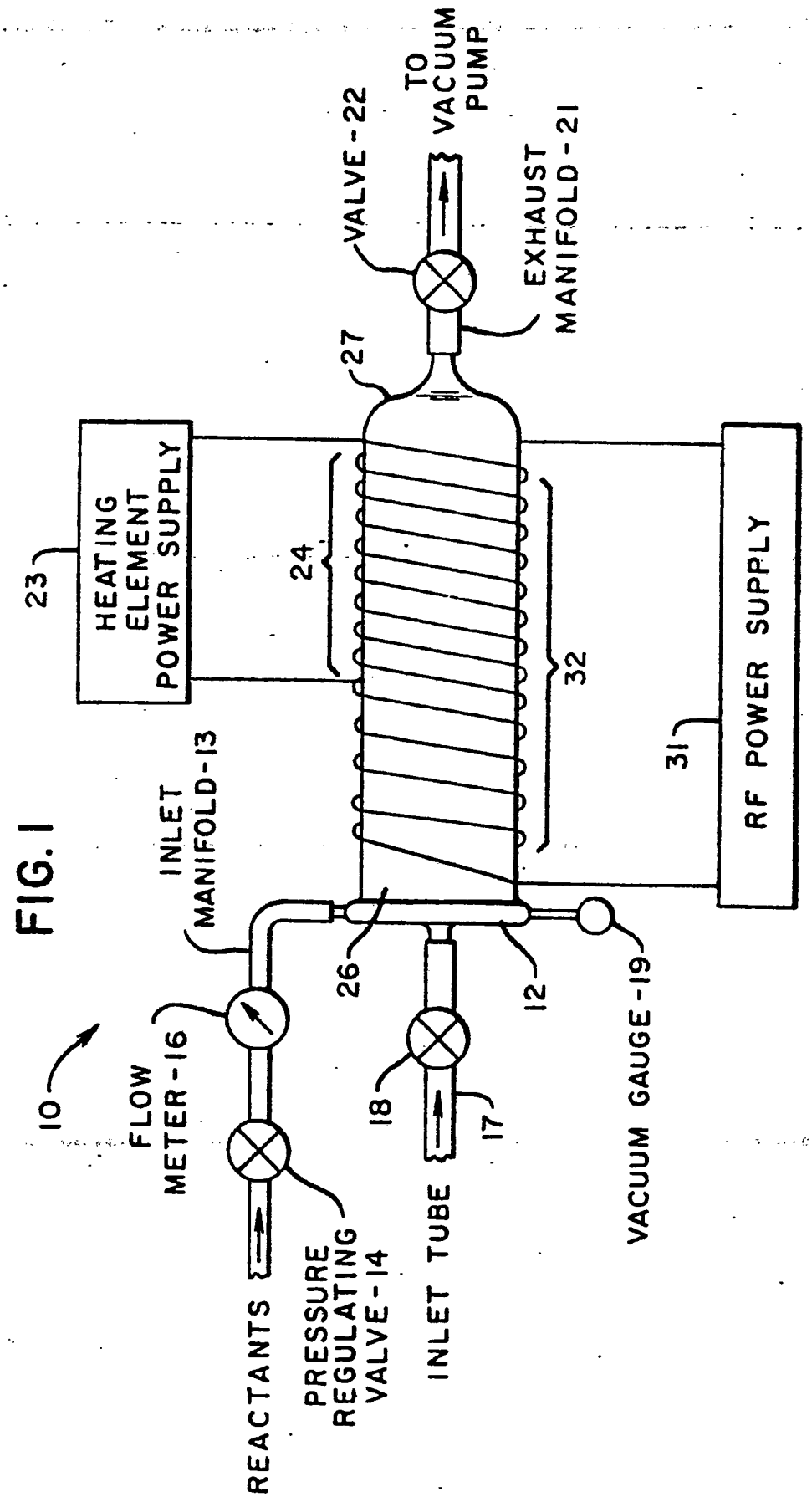


FIG. 1

FIG. 2

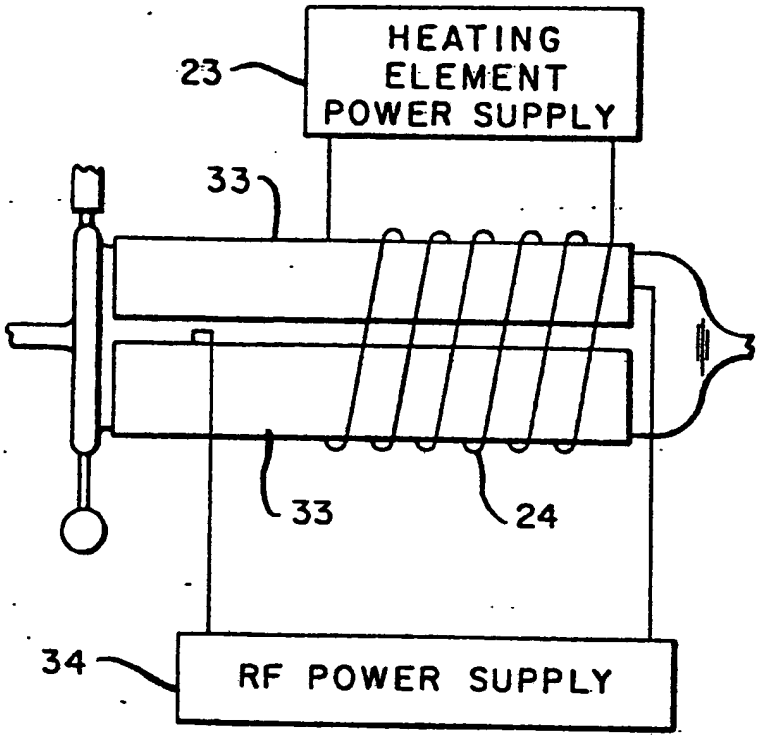


FIG. 3

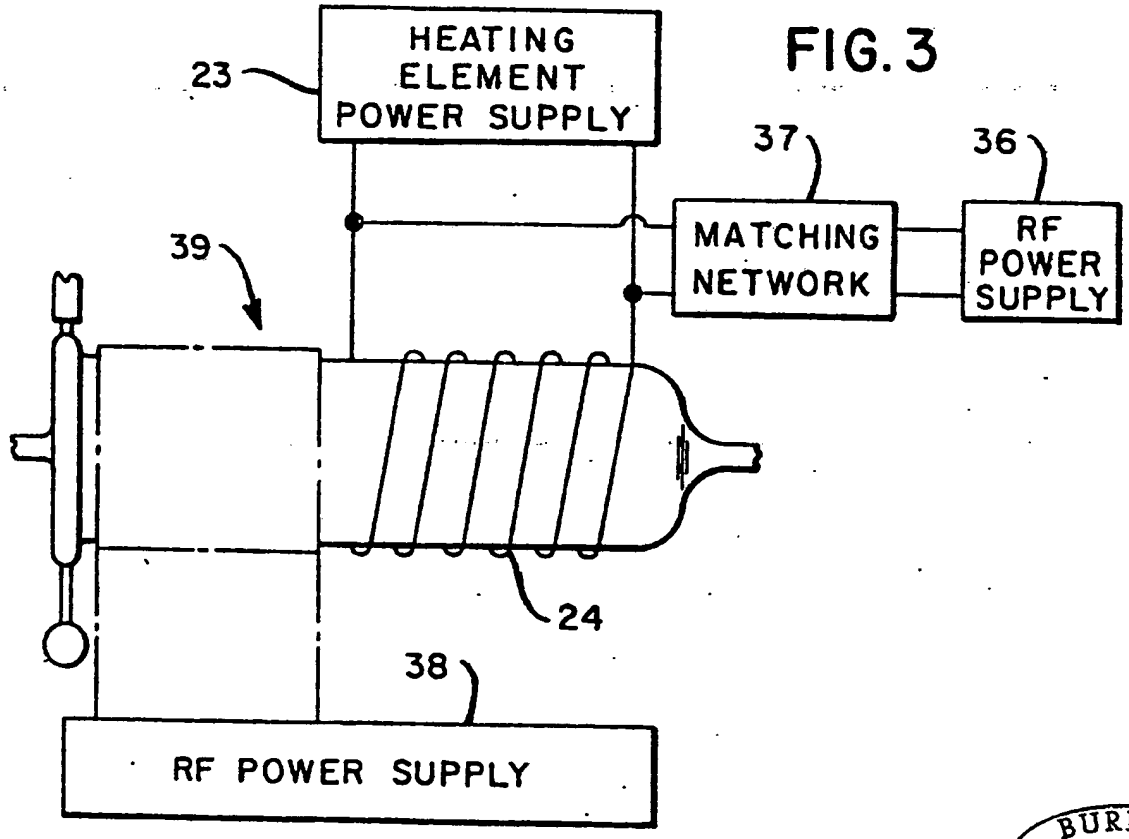


FIG. 4

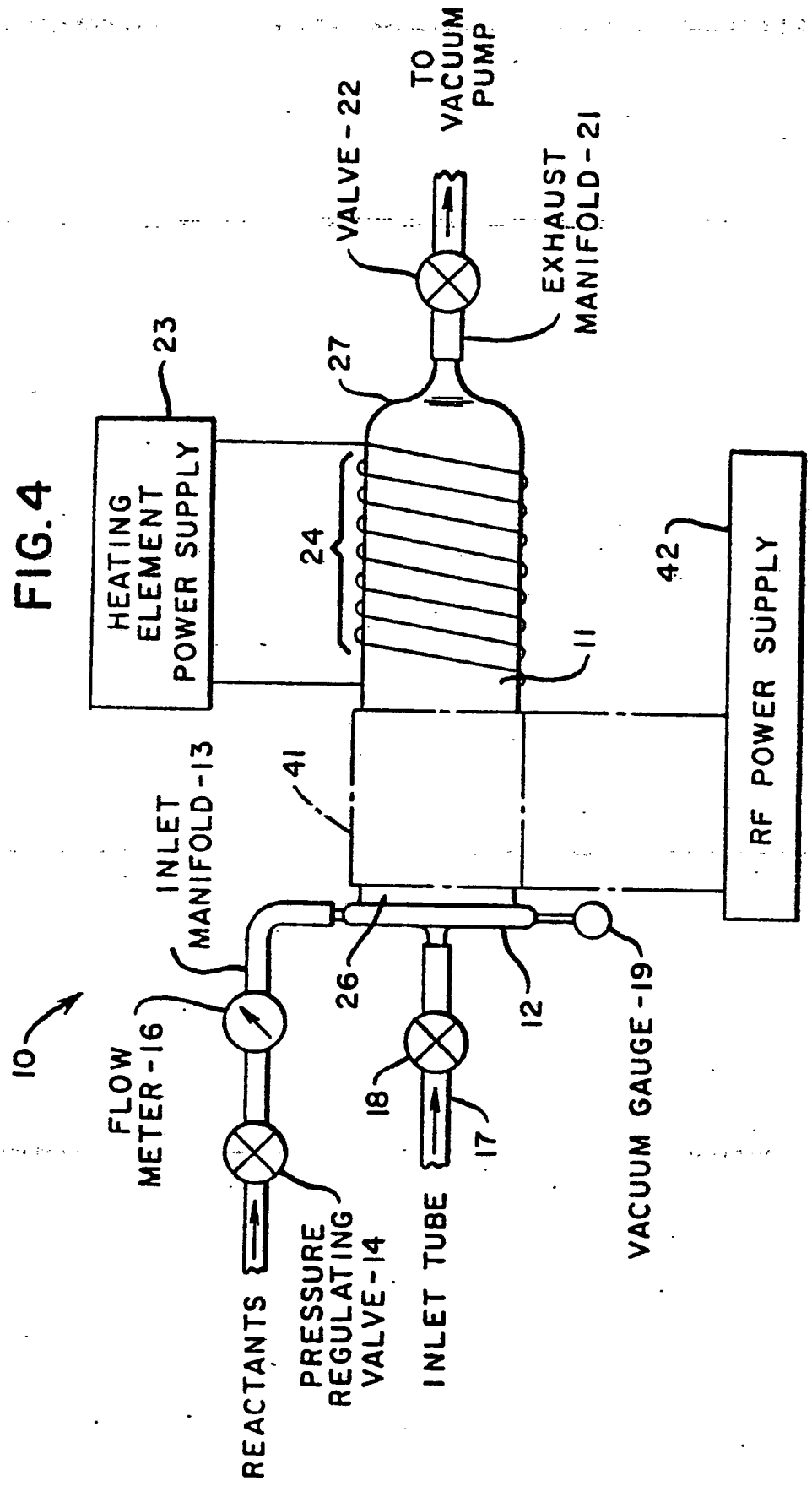
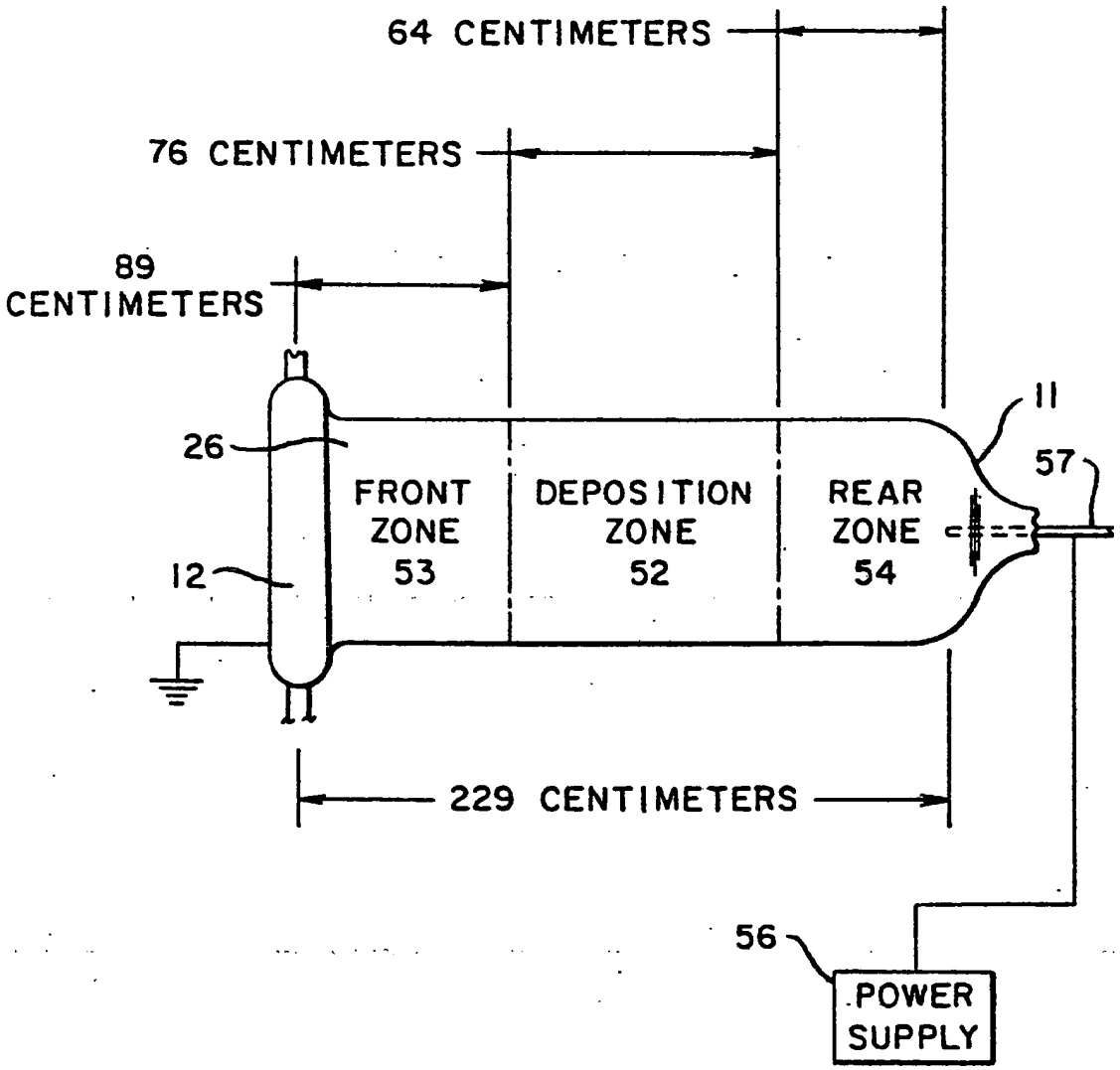


FIG.5



INTERNATIONAL SEARCH REPORT

International Application No PCT/US79/01127

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC WO 80/01363

INT. CL.[3] B08B 7/00,9/00; H01J 17/22

U.S. CL. 134/1,22R; 156/643; 313/231.3; 315/111.2

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
U.S.	134/1,22R; 156/204,643,646,662; 252/79.1; 204/164, 192E,192EC; 313/231.3; 219/121P,500; 250/531; 315/111.2,111.3

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
X,P	US,A, 4,138,306, PUBLISHED 06 FEBRUARY 1979, NIWA.	1-20
X	US,A, 4,123,663, PUBLISHED 31 OCTOBER 1978, HORIIKE.	1-20
X	US,A, 3,615,956, PUBLISHED 26 OCTOBER 1971, IRVING ET AL.	1-20
X	US,A, 3,795,557, PUBLISHED 05 MARCH 1974, JACOB.	1-20
X	US,A, 3,867,216, PUBLISHED 18 FEBRUARY 1975, JACOB.	4
X	US,A, 3,652,324, PUBLISHED 28 MARCH 1972, CHU ET AL.	8-9,18
A	US,A, 3,971,684, PUBLISHED 27 JULY 1976, MUTO.	1-20
A,P	US,A, 4,160,690, PUBLISHED 10 JULY 1979, SHIBAGAKI ET AL.	1-20

* Special categories of cited documents: [15]

"A" document defining the general state of the art

"E" earlier document but published on or after the international filing date

"L" document cited for special reason other than those referred to in the other categories

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but on or after the priority date claimed

"T" later document published on or after the international filing date or priority date and not in conflict with the application, but cited to understand the principle or theory underlying the invention

"X" document of particular relevance

IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
26 FEBRUARY 1980	07 MAR 1980
International Searching Authority [1]	**Signature of Authorized Officer [20]**
ISA/US	MARC L. CAROFF Marc L. Caroff

Form PCT/ISA/210 (second sheet) (October 1977)

FURTHER INFORMATION CONTINUED FROM THE SECOND SHEET

A,P	US;A, 4,158,589, PUBLISHED 19 JUNE 1979, KELLER ET AL.	1-20
A	US,A, 4,065,369, PUBLISHED 27 DECEMBER 1977, OGAWA ET AL.	1-20
A,P	US,A, 4,151,034, PUBLISHED 24 APRIL 1979, YAMAMOTO ET AL.	1-20
A	US,A, 4,123,316, PUBLISHED 31 OCTOBER 1978, TSUCHIMOTO.	1-20

V. ☐ OBSERVATIONS WHERE CERTAIN CLAIMS WERE FOUND UNSEARCHABLE [10]

This international search report has not been established in respect of certain claims under Article 17(2) (a) for the following reasons:

1. ☐ Claim numbers _____, because they relate to subject matter [12] not required to be searched by this Authority, namely:

2. ☐ Claim numbers _____, because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out [13], specifically:

VI. ☐ OBSERVATIONS WHERE UNITY OF INVENTION IS LACKING [11]

This International Searching Authority found multiple inventions in this international application as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims of the international application.

2. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims of the international application for which fees were paid, specifically claims:

3. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claim numbers:

Remark on Protest

☐ The additional search fees were accompanied by applicant's protest.

☐ No protest accompanied the payment of additional search fees.